Project Report: Image Filtering and Noise Analysis

The primary goal of this project was to investigate various image filtering techniques and their effectiveness in reducing noise while maintaining image quality. I evaluated the clean images and analyzed them by comparing them with the filtered images. The study aimed to identify the best approaches for improving image clarity, particularly in the presence of Gaussian noise.
The project also explored the calculation of image quality metrics, specifically the Root Mean Square Error (RMSE) and Peak Signal-to-Noise Ratio (PSNR), to quantitatively assess the performance of various filters (Mean, Smart, Spatial Domain).

Objectives

To design functions for evaluating RMSE and PSNR between images.
To create a method for adding Gaussian noise to an image.
To implement mean filtering and smart filtering techniques.
To conduct a comparative analysis of filtering methods based on their ability to improve image quality.
To document findings and propose an optimal filtering strategy.

The project began by establishing functions to calculate RMSE and PSNR. RMSE quantifies the average difference between pixel values of the original (clean) image and the processed image, while PSNR offers a logarithmic measure of the peak error. These metrics provide a comprehensive view of image quality, allowing for effective comparisons.

To simulate real image conditions gaussian noise was added to the clean images. The standard deviation of the noise was determined as a fraction of the clean image's standard deviation, which ensured that the noise characteristics were appropriate for the specific image being analyzed. In the slides it was specified that an STD of 0.1 to 0.5 was acceptable.

Filtering Techniques

Mean Filtering: This technique replaces each pixel value with the average of its neighbors within a 3x3 window. It is effective in reducing random noise but may also blur image details.

Smart Filtering: This method employed a weighted kernel to consider pixel intensity variations, allowing for better preservation of edges and fine details while still reducing noise.

Experimental Process

- Image Selection: A clean image was chosen as the base for noise addition.

- Noise Generation: Two versions of the noisy image were created using Gaussian noise with different standard deviations.
- Application of Filters: The mean and smart filters were applied to the noisy images.
- Evaluation: RMSE and PSNR values were computed for both the noisy and filtered images, allowing for a detailed performance comparison.

The mean filter provided a basic level of noise reduction but often resulted in blurring and loss of detail.
The smart filter demonstrated superior performance in maintaining image clarity, achieving lower RMSE and higher PSNR values compared to the mean filter.

Additionally, the project included an exploration of an alternative filter kernel aimed at outperforming the smart filter.

Kernel 1 (first run & second run)

kernel -> [1 | 2 | 1]
[2 | 4 | 2]
[1 | 2 | 1]

Normalization -> 1/16

Kernel 2 (first run)

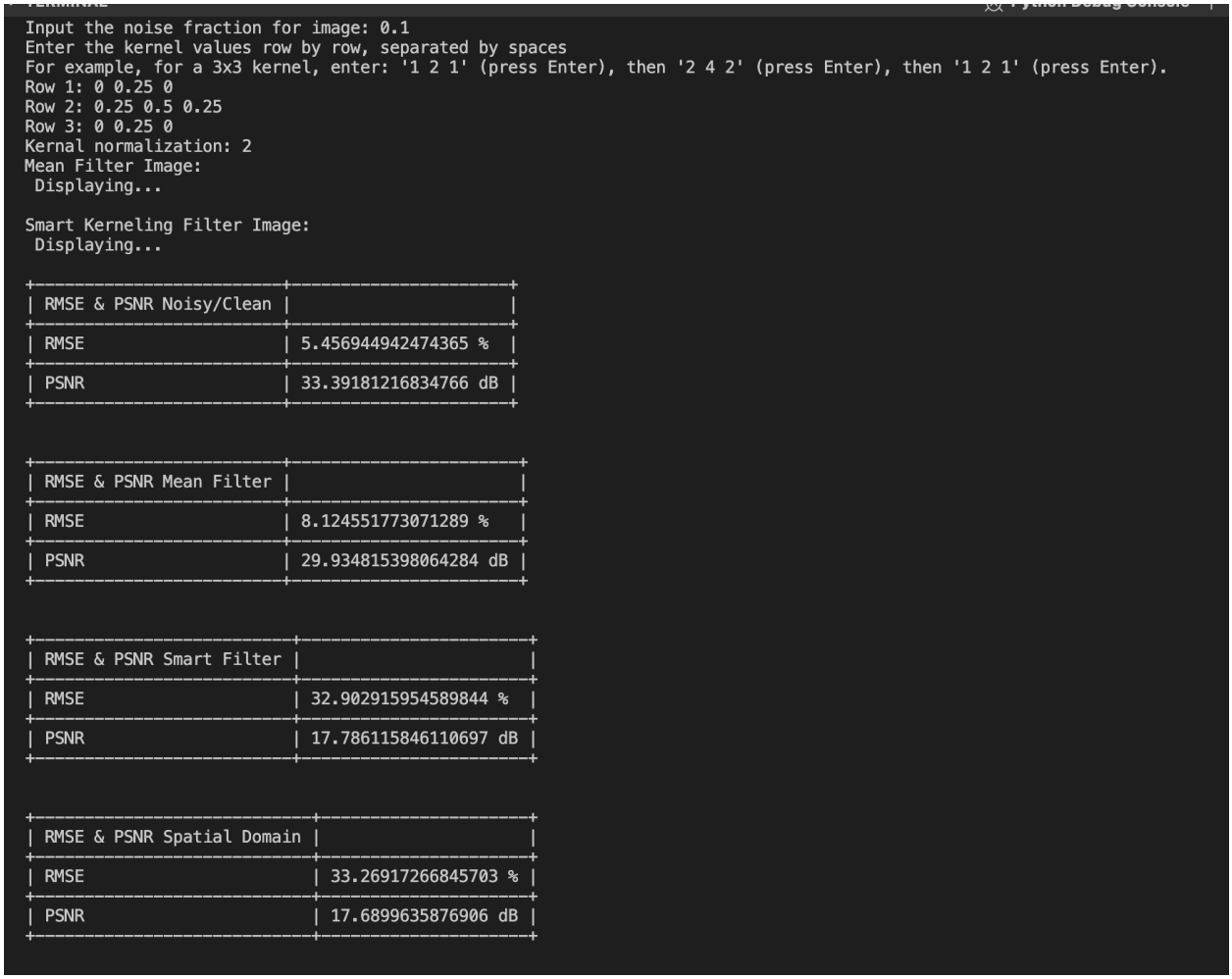
kernel -> [0.0625 | 0.125 | 0.0625]
[0.125 | 0.25 | 0.125]
[0.0625 | 0.125 | 0.0625]
Normalizing -> 1/16
The PSNR was significantly decreased in both the smart filter and spatial domain filter.

```
For example, for a 3x3 kernel, enter: '1 2 1' (press Enter), then '2 4 2' (press Enter), then '1 2 1' (press Enter).
Row 1: 0.0625 0.125 0.0625
Row 2: 0.125 0.25 0.125
Row 3: 0.0625 0.125 0.0625
Kernal normalization: 16
Mean Filter Image:
 Displaying...

Backend macosx is interactive backend. Turning interactive mode on.
Smart Kerneling Filter Image:
 Displaying...

+--------------------------+-----------------------+
| RMSE & PSNR Noisy/Clean |                       |
+--------------------------+-----------------------+
| RMSE                     | 5.462512016296387 %   |
+--------------------------+-----------------------+
| PSNR                     | 33.382955502087206 dB |
+--------------------------+-----------------------+


+--------------------------+-----------------------+
| RMSE & PSNR Mean Filter |                       |
+--------------------------+-----------------------+
| RMSE                     | 10.023574829101562 %  |
+--------------------------+-----------------------+
| PSNR                     | 28.11035087132584 dB  |
+--------------------------+-----------------------+


+--------------------------+-----------------------+
| RMSE & PSNR Smart Filter |                       |
+--------------------------+-----------------------+
| RMSE                      | 118.4756851196289 %  |
+--------------------------+-----------------------+
| PSNR                      | 6.658219032457088 dB |
+--------------------------+-----------------------+


+---------------------------+----------------------+
| RMSE & PSNR Spatial Domain |                      |
+---------------------------+----------------------+
| RMSE                       | 118.91958618164062 % |
+---------------------------+----------------------+
| PSNR                       | 6.625735823272141 dB |
+---------------------------+----------------------+


Do you want to process another pair of files? (Y/N): N
```

This kernel weight is a lot better than the next kernel weight as the PSNR (Peak Signal Noise Ratio has decreased a lot) from < 7 % (original ~ 28%).

Kernel 2 (second run)

kernel -> [0 | 0.25 | 0]
[0.25 | 0.5 | 0.25]
[0 | 0.25 | 0]
Normalizing -> 1/2
It was found that PSNR is lower in the smart filter and spatial domain filter.



This kernel weight is not as good compared to the other kernel weight as the PSNR (Peak Signal Noise Ratio) is < 18 % (original ~ 28%).

Preliminary results indicated promising improvements in PSNR, suggesting that further optimization of filtering techniques could lead to enhanced image quality.

This project successfully demonstrated the impact of different filtering techniques on noisy images. The smart filter emerged as the most effective method for noise reduction while preserving image details. The quantitative analysis through RMSE and PSNR provided a solid foundation for assessing filter performance between clean image -> Gaussian Image, and clean image -> filtering.

All the image outputs are located in ./project_2/image_output in both Kernel_1& Kernel_2 each with first and second run